

Optical coherence tomography imaging to analyze biofilm thickness from distal to proximal regions of the endotracheal tubes

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ABSTRACT

The development of nosocomial ventilator-associated pneumonia (VAP) has been linked to the presence of specific bacteria found in the biofilm that develops in intubated endotracheal tubes of critical care patients. Presence of biofilm has been difficult to assess clinically. Here, we use Optical coherence tomography (OCT), to visualize the biofilm at both the proximal and distal tips. Ultimately, the goal will be to determine if OCT can be a tool to visualize biofilm development and potential interventions to reduce the incidence of VAP.

Keyword list: Optical Coherence Tomography, Endotracheal Tube, Biofilm, Ventilator Associated Pneumonia, Translational, ETT, OCT, VAP

1. INTRODUCTION

When a patient must stay in a hospital for a prolonged period of time, their risk of contracting a nosocomial infection increases. Ventilator associated pneumonia (VAP) is one of the most frequent infections of patients in the ICU. This risk can be as high as 65% when the patient must be mechanically ventilated [1].

The bacteria that can cause VAP are found in the biofilm that accumulates in the patient's endotracheal tube. These bacteria begin to stick to the inner wall of the endotracheal tube due to the texture of the tube or hydrophobicity. As more bacteria accumulate and thrive, they begin to secrete a polysaccharide matrix. Over time, the accumulation of the polysaccharide matrix and bacteria that make up the biofilm, can partially detach and be aspirated [2]. There longer a patient is intubated, the more biofilm can form. In previous studies, the presence of biofilm was seen within 24 hours with 83% of the tubes analyzed testing positive for some bacteria [3].

Aspirates of the biofilm in the ETT tube can be collected and tested to detect the presence of bacteria, however, to visualize the progression of the biofilm development can help reduce the risk of contracting VAP. Seeing how far along the biofilm has develop can allow physicians the opportunity to decide when an ETT should be replaced before the biofilm detaches from the ETT and falls into the patients lungs.

Some studies have begun to image the ETT with Computerized tomography (CT) [4]. While MicroCT successfully imaged the biofilm in the ETT, we looked to Optical Coherence Tomography (OCT). Oct offers an imaging modality that is non-ionizing and less harmful when used in the clinic. In a previous study, it was demonstrated that OCT was able to image the biofilm in the tubes [5]. The images were compared to a Scanning Electron Microscopy (SEM) image to confirm bacterial and biofilm presence inside the tube. Since OCT was able to successfully image the biofilm, here, we look to see if we can use OCT to analyze the progression of Biofilm across the ETT. Previous studies indicate that biofilm tends to accumulate at the distal (tip) end of the ETT and decreases as you move toward the proximal (ventilator

side) end. Using OCT, we plan to see an increase of unobstructed airway area along the length of the tube. If biofilm is collecting at the distal end, there should be a smaller unobstructed airway area relative to the proximal end.

2. METHODS AND MATERIALS

2.1 Imaging Technique

The ETT were retrieved from the UCI Medical Center Intensive Care Units within 24 hours of the patient's extubation. Patients were not pre-selected for the study, so the tubes used came from patients whom were possibly weaned off the tube, changed to a tracheostomy tube, or even passed away. The ETT was placed in a clear, minigrip bag with a moist paper towel to maintain a closed, moist environment. The patient's age, length of extubation, history of pulmonary organisms during time of intubation, if they developed VAP, and reason for extubation were recorded. The tube was then brought to the laboratory to image using our OCT system [6]. The OCT system has a 1310 nm center wavelength swept source with a 50 kHz sweep rate. It also uses a 100 nm bandwidth laser source with a Michelson interferometer. The probe has a 100 μm axial resolution and a 112 μm resolution. A reference arm in the system used an acousto-optic modulator, providing a 150 MHz carrier frequency. The tube was secured to a stage that held the probe straight at 2 pressure points. The stage also held the probe sheath at 2 points in an attempt to center the probe in the tube as much as possible [Figure 1]. Imaging began at the distal (tip) end of the tube and moved 20 cm toward the proximal (ventilator-side) end of the tube.

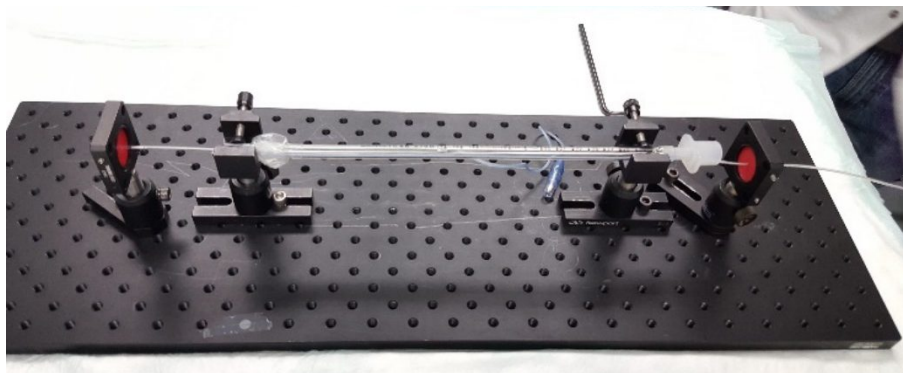


Figure 1. This is the stage in which the tube was held in place and the probe was held in a more stable and centered position within the tube. The red circular portions are 3-d printed cylinders that have a hole small enough to snugly fit the sheath.

2.2 Image Analysis

The data collected from the OCT images contained intensity values per pixel. Each B-scan has 1000 A-Lines, and each tube produced 800 B-scans over 20 cm. Each package of data was processed through a MATLAB code that analyzed each image to find the unobstructed area of the ET Tube. First, the user must manually find the row where the sheath begins. This can be done by plotting the first row of intensity values and finding the peak intensity that corresponds to the sheath, then finding the next 0 intensity point to start analyzing the image past the sheath. Then, the code uses Sobel edge detection to emphasize the edges of the biofilm and ETT. A 12 by 12 window then scans over the image column by column, taking an average of values until it reaches a threshold indicating where the biofilm starts. This threshold is found manually as well to find the best threshold per set of images. This gives us the number of pixels between the sheath and the biofilm. Since we know that each pixel is about 10 micrometers, we can convert the number of pixels to a radius length per A-line. The radius can then be put in a formula to find the approximate segment of area that is unobstructed by biofilm. Then we can sum up each segment of area to find the total unobstructed area of airway in the ETT. The formula is as follows:

$$B_i = \sum_1^{A-line_{total}} A_i = \frac{360}{A-line_{total}} \pi r_i^2 \quad (1)$$

where B_i is the total unobstructed area of the ETT. A_i is the area unobstructed per A-line. Summing up all the A-line areas will give the total unobstructed area of the ETT. Figure 2 illustrates an image of an ETT with biofilm outlined by the code.

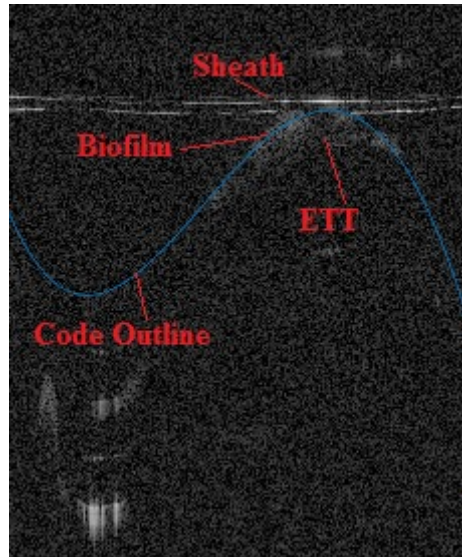


Figure 2. This image illustrates the polynomial generated by the code, which also allowed us to interpolate data when it was not captured by the OCT system.

2.3 Statistical analysis

For each tube imaged, the values of area found per B-Scan were graphed to illustrate the trend across the ETT. A linear regression line was also included to visualize the general trend. Categorical data was collected to consider other factors that could influence the development of biofilm. The R^2 , linear regression line equation, variance and standard deviation was included per tube as well. While we did not keep the ETT size constant, we instead looked at the unobstructed airway spaces as we moved along the ETT instead to observe a trend.

3. Results

Below are the graphs and data associated to the tubes that were imaged for the study. Unfortunately, not all the tubes were able to be properly processed due to the inability for the code to process images that had too low resolution, so they are not included in this study. It is also important to note that none of the patients whom these tubes came from, contracted VAP.

Table 1. Categorical data collected with extubations

| Tube | Length of Intubation | Patient Age | Patient Sex | Pulmonary Organisms | Reason of extubation |
|-----------|----------------------|-------------|-------------|---------------------|----------------------|
| Control 1 | 0 Days | 0 | N/A | None | N/A |

| | | | | | |
|--------|--------|----|--------|---|------------|
| Tube 1 | 4 Days | 41 | Male | Chronic cough, SIRS, Mediastinal Emphysema, Pericardial effusion, Mediastinitis | Weaned Off |
| Tube 2 | 4 Days | 67 | Female | None | Weaned Off |
| Tube 3 | 1 Days | 41 | Female | None | Weaned Off |

Table 2. Statistical Data per tube

| Tube | R ² | Linear Regression formula | Variance | Standard Deviation |
|---------|----------------|---------------------------|----------|--------------------|
| Control | 0.006 | $y = 1E-05x + 0.0656$ | 0.000207 | 0.01440 |
| Tube 1 | 0.063 | $y = -0.0001x + 0.2309$ | 0.008551 | 0.09247 |
| Tube 2 | 0.1235 | $y = 7E-05x + 0.1175$ | 0.002118 | 0.04602 |
| Tube 3 | 0.0743 | $y = 4E-05x + 0.1354$ | 0.001130 | 0.03362 |

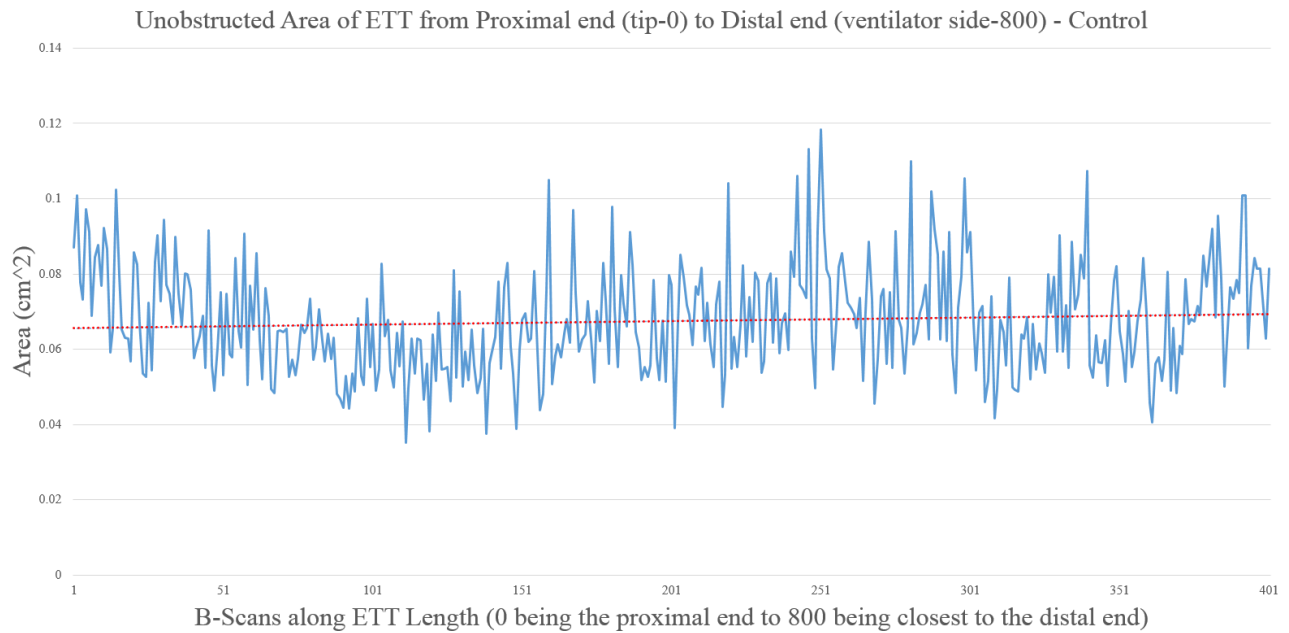


Figure 3. Graph of Control tube

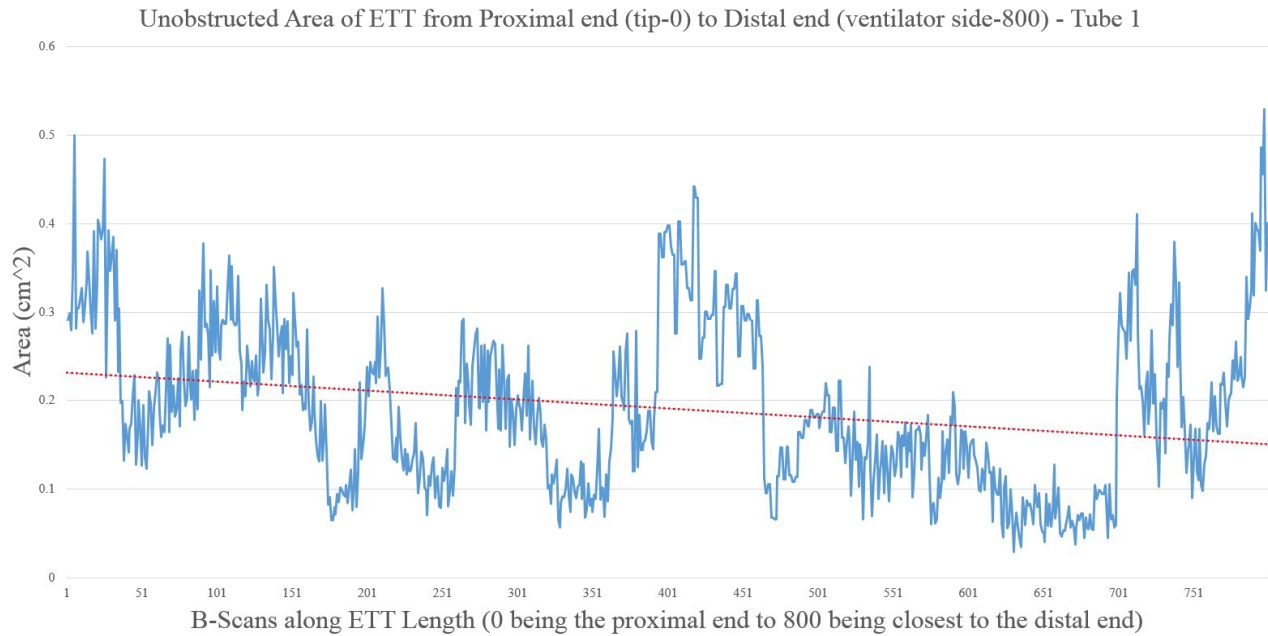


Figure 4. Graph of Tube 1

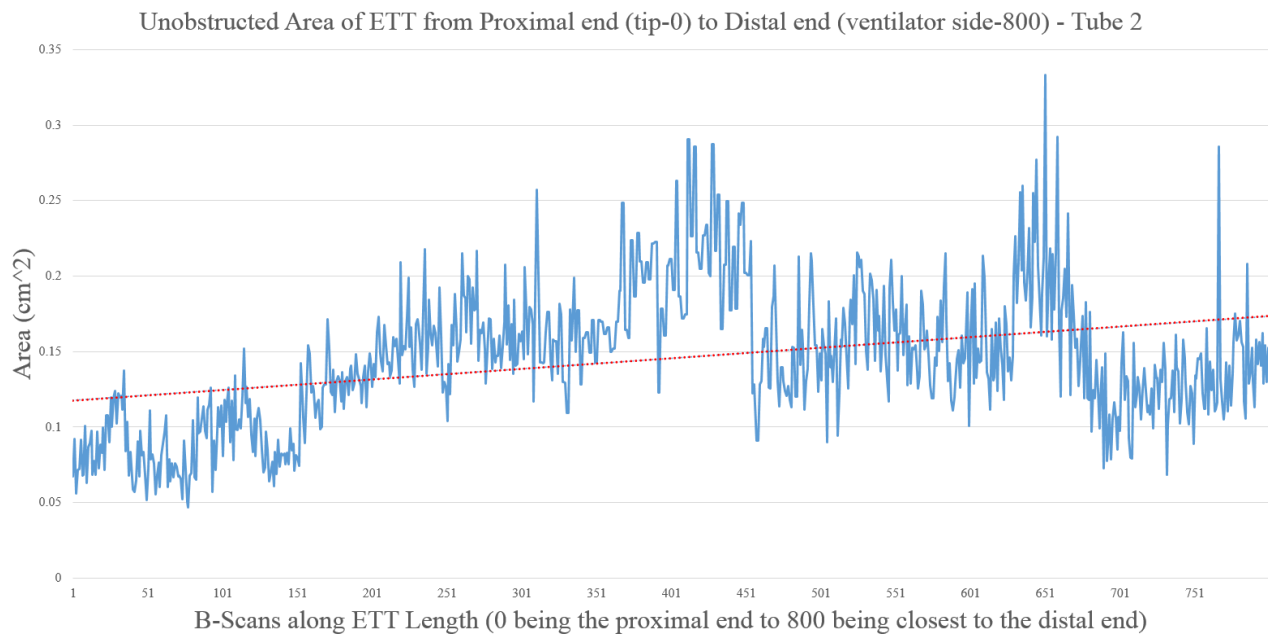


Figure 5. Graph of Tube 2

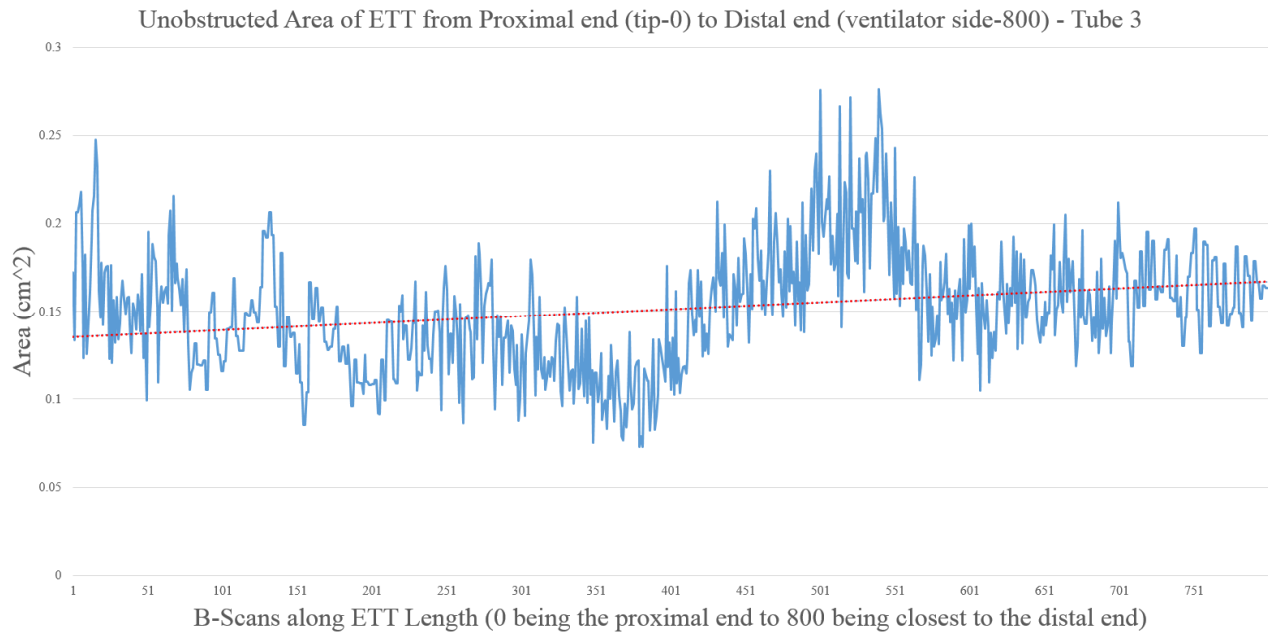


Figure 6. Graph of Tube 3

4. Discussion

In this study, we looked at 1 control tube and 3 ETT collected from the medical clinic, imaged within 24 hours, and processed via a MATLAB code. The control tube illustrated the general even trend that can be observe in an unused, clean tube. Of the following three tubes, only 2 of the three followed the trend of previous research. However, looking at the areas found per B-scan, we can visualize the fluctuations of biofilm across the tube. For the tube that didn't match, there was one significant portion of the tube at the proximal end that had a decrease in unobstructed area. Without this portion, the formula changes to $y = 7E-06x + 0.2142$, which changes the slope to a positive slope. Though biofilm was present, no VAP was contracted.

5. Future Work

Without many restrictions on the selection of the tubes, there can be no correlation drawn from age or length of intubation from this study. Controlling for those parameter can analyze their effect on the biofilm formation and can be compared to the secretion volume density and patient age correlation found in other research [4]. With OCT being non-ionizing, it would be best to go into the clinic and analyze biofilm formation over time of patients intubated. With confirming the development of biofilm at the distal end, it would also be important to look at what conditions within the ETT while the patient is intubated promote biofilm development at the distal end over the proximal end. Furthermore, optimizing the processing abilities of the MATLAB code and the OCT system can facilitate physician's ability to diagnose and assess the biofilm development in intubated-patients, decreasing their chances of contracting VAP.

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